Mamm Creek Field Case History
Piceance Basin Colorado

An Unconventional Resource Development Example of Stray Gas Migration

Isolated Event

Or

More Pervasive Issue of Broader Concern?

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Sources and Acknowledgements

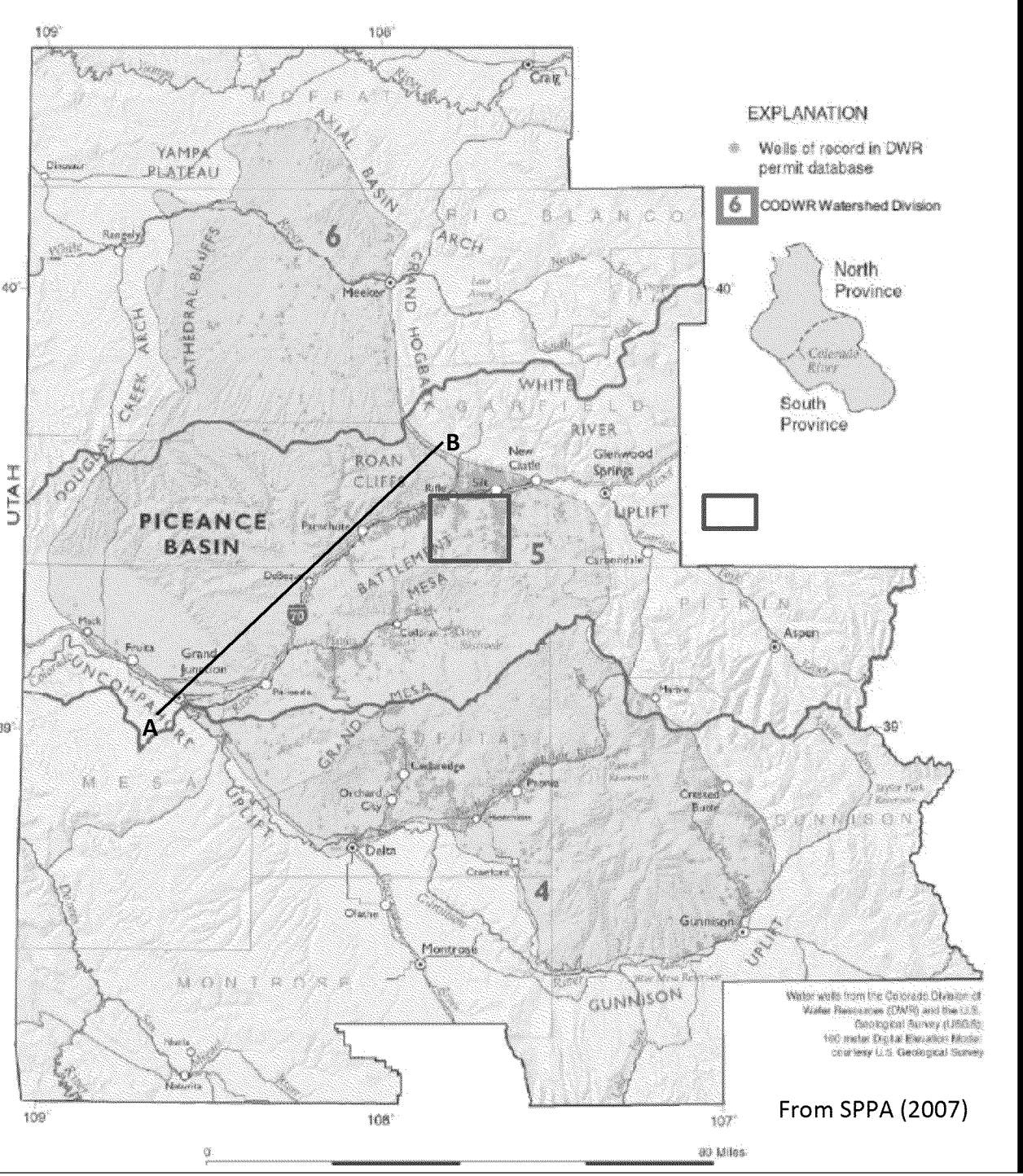
- Colorado Oil and Gas Conservation Commission (COGCC)
- (Various Piceance Basin Reports/Data from website at **http://cogcc.state.co.us**)
  - Stuart Ellsworth – Engineering Manager
  - David Andrews – Northwest Area Engineering Supervisor
  - Tom Kerr – Acting Director
  - Crescent Consulting LLC; Reed Energy Consulting LLC; Roge, LLC; EMCPA Study (2011)
  - COGCC Response Memo to Crescent Consulting LLC et al Concl. & Rec. (2011)
- Garfield County Board of Commissioners
  - URS Corp (Phase I Hydrogeologic Characterization - 2006)
  - SS Papadopulos & Associates (Phase II Hydrogeologic Study - 2008)
  - Dr. Geoffrey Thyne, Univ. of Wyo. (Review of Phase II Hydrogeologic Study - 2008)
  - The Walter Environmental Group (Joint Study and Structural Analysis)
- T. Albrecht (unpub. Masters Thesis, CSM)
- S.S. Papadopulos & Associates (Evaluation of Thyne Review - 2008)
- Encana Oil and Gas (USA)
  - Rule Engineering, LLC (West Divide Seep Remediation and Monitoring Results - 2011)
  - Universal Geoscience Consulting Inc. (Review of Thyne Interpretations)
- Bill Barrett Corporation
  - HCItasca Denver, Inc. (Review of Thyne Interpretations)

Mamm Creek Field Play Elements

1. Reservoir: Tight Gas Sands (Williams Fork Fm. of Up. Cret. Mesaverde Gp.)
2. Stimulation: Requires Hydraulic Fracturing of vertical pay penetrations
3. Hydrocarbon: Gas and Gas Condensate prod. from 3000' to 7000' depth
4. Field Area: 100+ sq. mi. (parts of 4 townships)
5. Wells: 2100+ on 10 to 20 acre (bottom hole) spacing from multi-well pads (interspersed with ~ 500 water supply wells – all types)
6. Surface Geology: Fractured/jointed* Wasatch Fm. directly overlies WF
7. Operators: EnCana, Bill Barrett Corp and ~ 34 others
8. Major Structure: Divide Creek Anticline (NW plunge - EMCPA)
9. Nuisance Gas: Shallow low pressure gas commonly occurs in Wasatch Fm.
10. Significant "Event": Release to surface of gas and condensate from EnCana Schwartz 2-15B (02) well (Lost Circ. Zones, Wasatch Gas Kick)
11. Major Issue: "Claims" and concerns of methane contamination of groundwater supplies [isolated event(s) or more pervasive long-term impacts associated with gas drilling activity?]

Mamm Creek Field – Why the Attention?
(Unconventional Resource Play Context)

1. Schwartz 2-15B (02) "Unique Event" – Escape of methane gas & condensate to surface (West Divide Creek Seep 3000 ft. distant) after failed cement job – (unrelated to hydraulic fracturing process).
2. Geologic Conditions result in positive bradenhead pressures on relatively high percentage of completed wells (35%) – requires post-completion monitoring and evaluation for well remediation as needed **(> 150 psi)**
   a.) COGCC established policy-based areas w/more strict requirements
      1. Revised Cementing Requirements (NTO Policy Areas)
      2. Bradenhead Monitoring (NTO Policy Areas)
      3. Well Remediations in East Mamm Creek Producing Area (EMPCA)

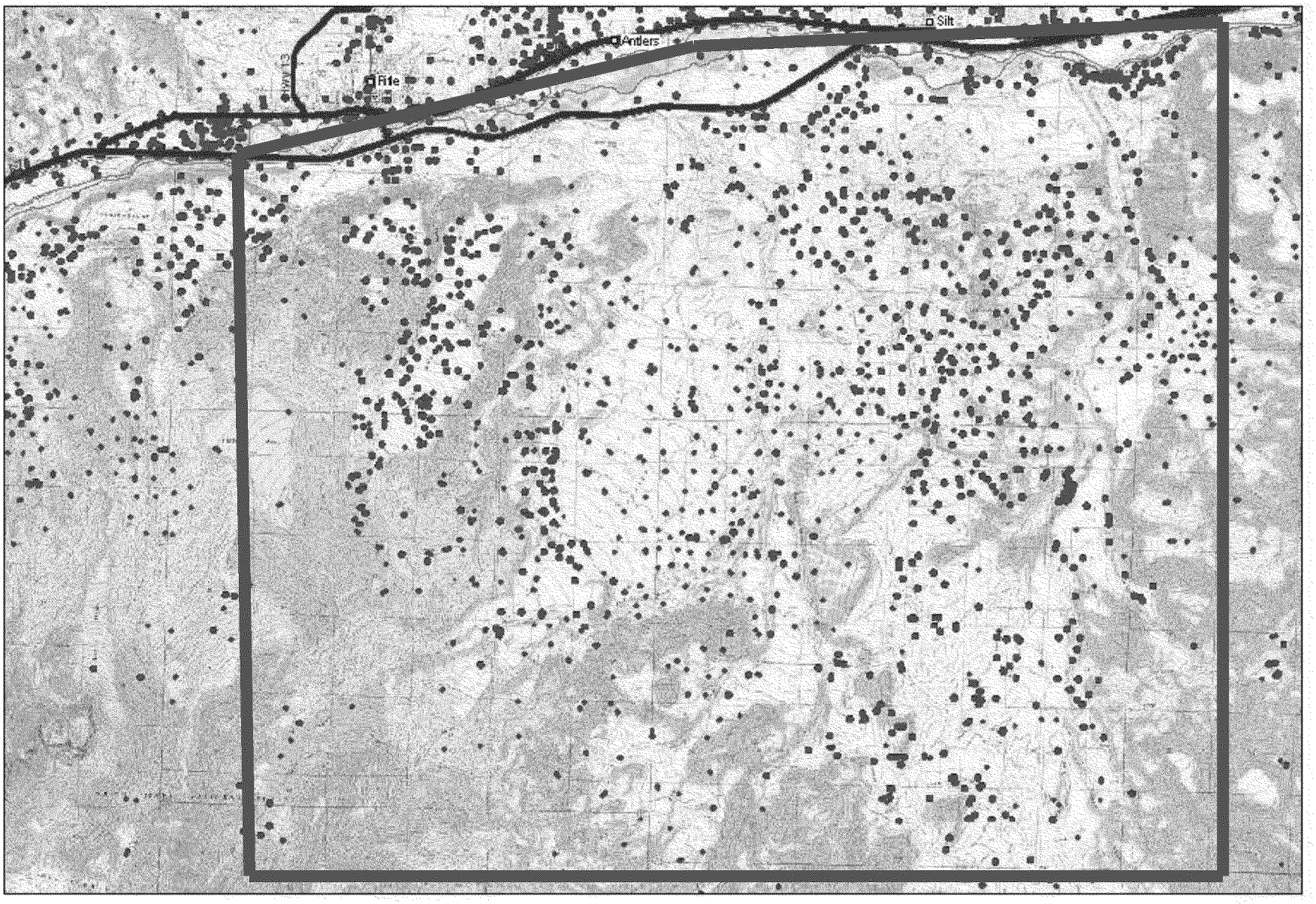


From SPPA (2007)

Extent of Piceance Basin, Western Colorado (Colorado Geol. Survey, 2003)

- 7100 sq. mi. basin (brown)
- 100+ sq. mi. Mamm Cr. Area
- Oil and Gas production Upper Cretaceous Williams Fork Fm. (> 2100 gas wells)
- Depth to gas is 3000 to 7000 feet across play area
- Wasatch Fm. is primary bedrock aquifer < 600' (yields < 10 gpm)
- Alluvial gravels along Colorado River (to north) and tribs. provide much greater yields
- 4+ Phases of Water Quality studies conducted in Mamm Creek and surrounding areas

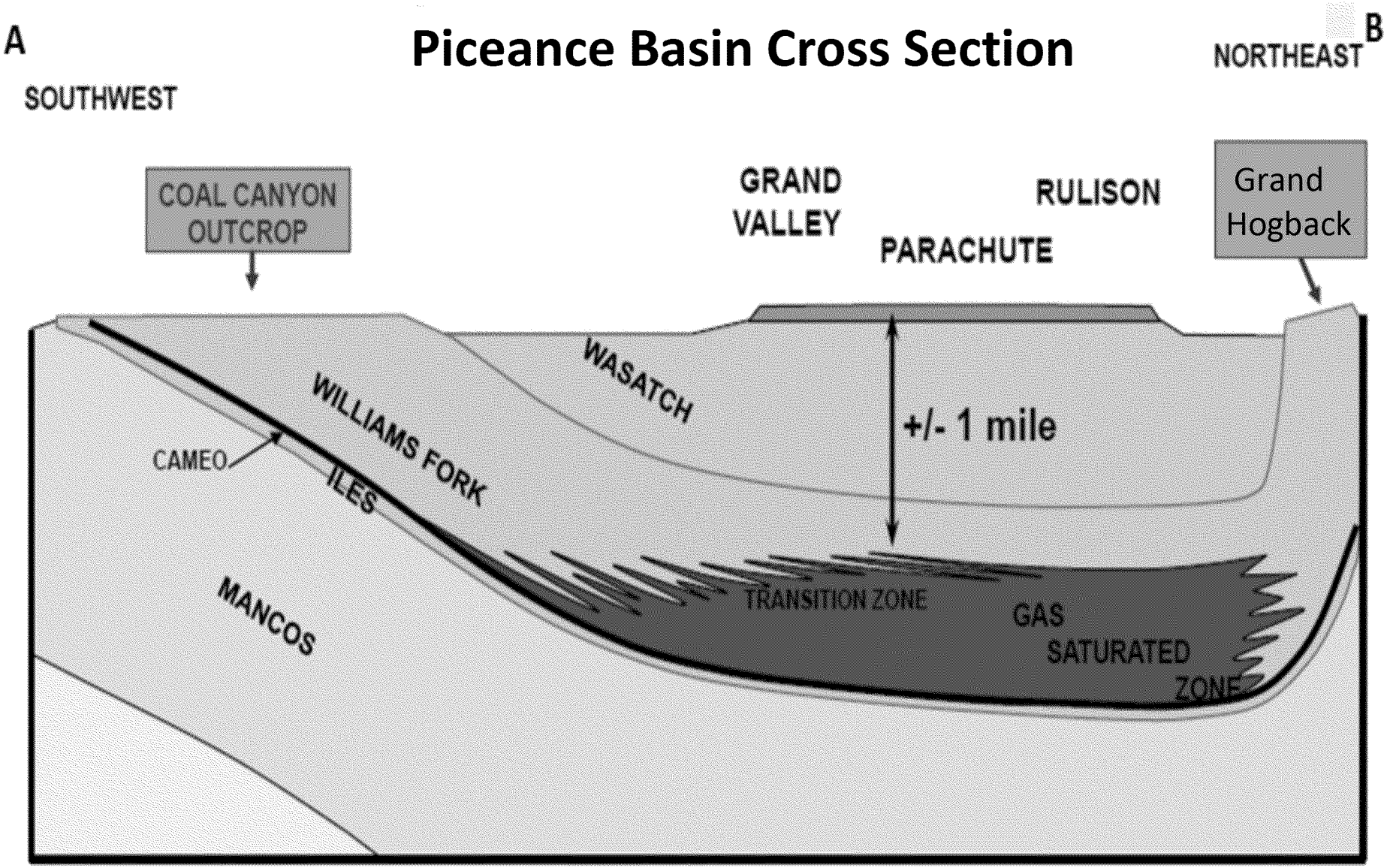
Water Well and Oil and Gas Locations



- 500 Water Wells (all types – max. depth 600')
- 2100 + Gas Wells/Well Pad Locs.

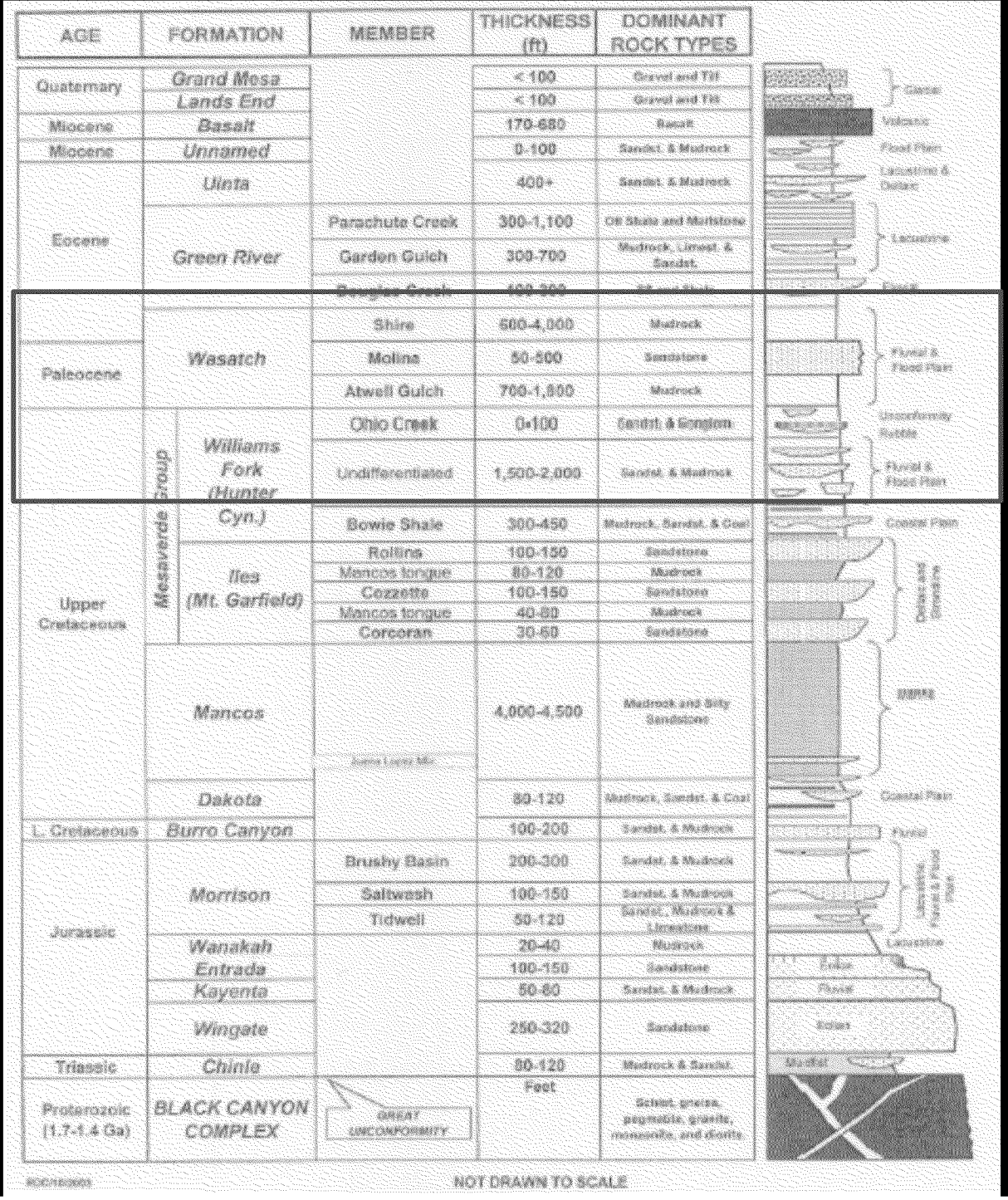
from COGCC,
Gintautas

Piceance Basin Cross Section



- Formations being hydraulically fractured are deep underground
- Drinking water is shallow in comparison

From EPA HF Workshop, Feb. 2011 (Foreman)



Geologic Section for Western Colorado

Mamm Creek Area Geologic Section of Interest (red outline)

Outcrop: Tertiary Wasatch Fm.

Williams Fork Fm.

Fluvial & Floodplain dis-continuous sands/sand lenses –tight, highly "compartmentalized" sand reservoirs require small well spacings to exploit.

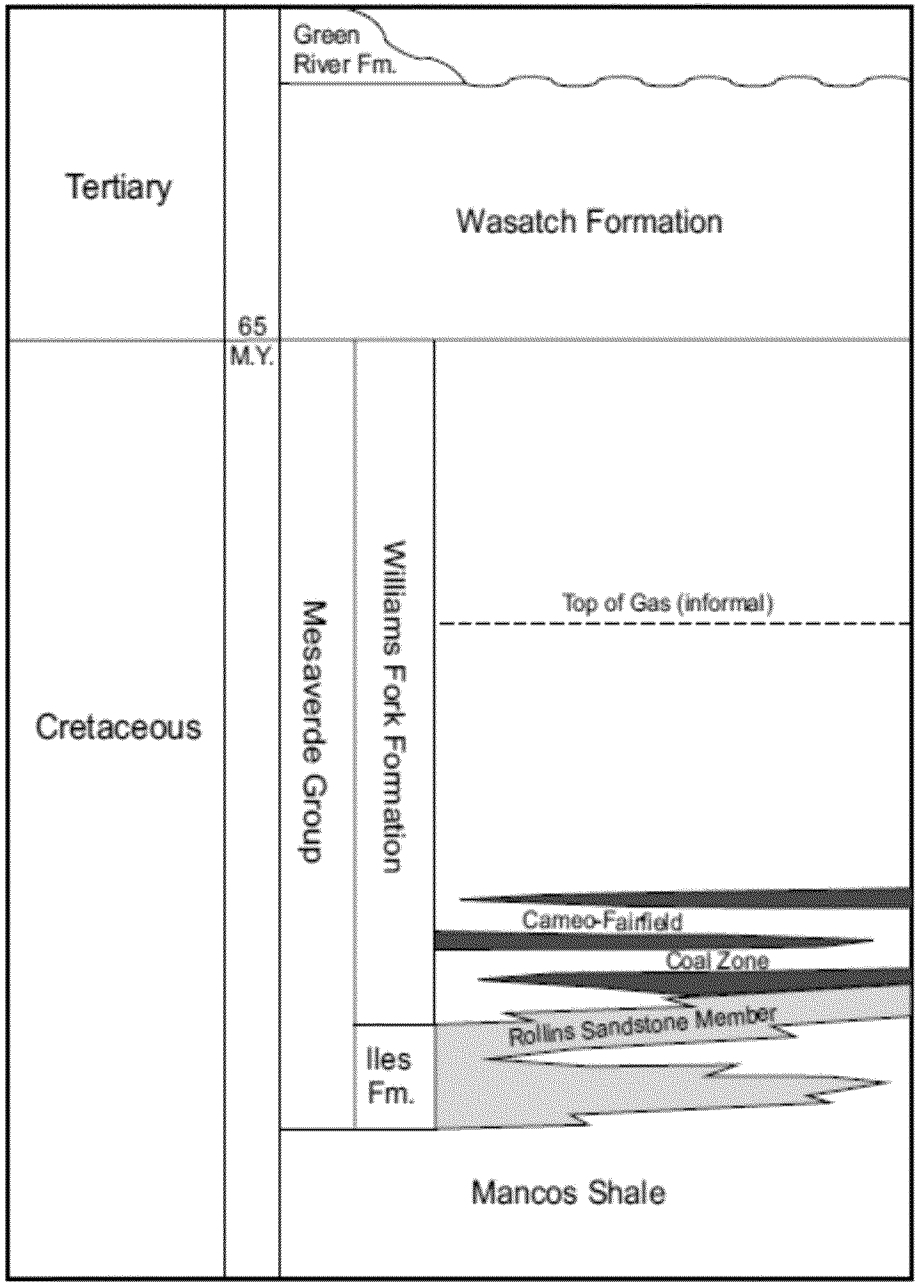
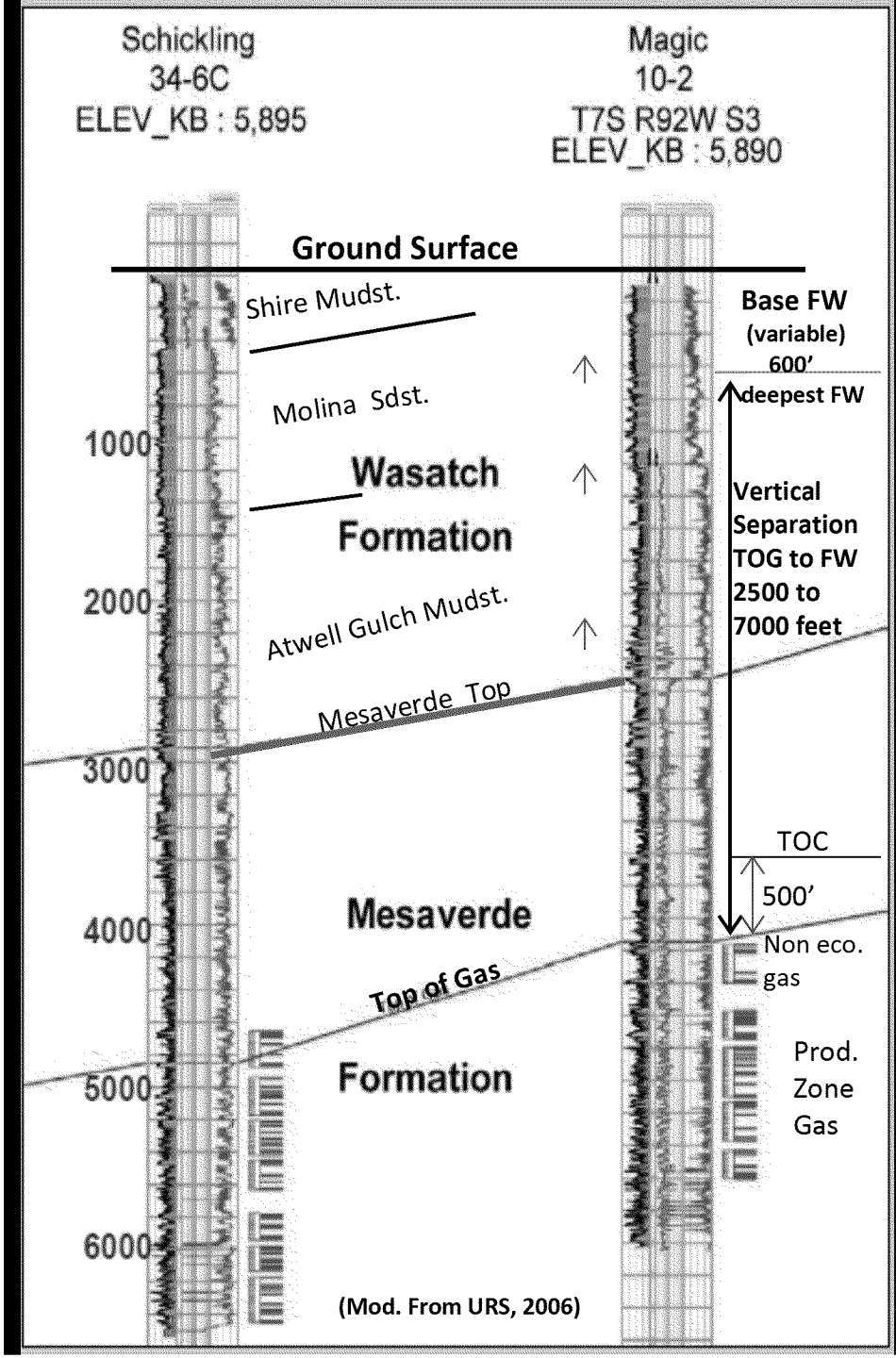
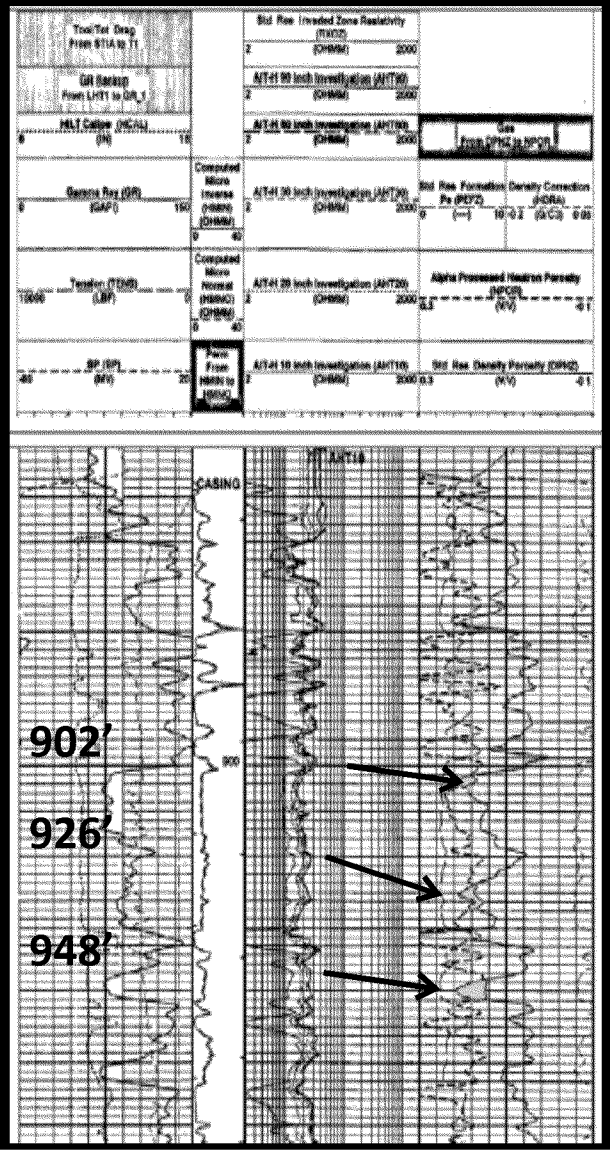


Figure 2.1 Simplified Stratigraphy for Mamm Creek Study Area. No vertical scale. Modified from Carroll (2003) and Johnson and Flores (2003).

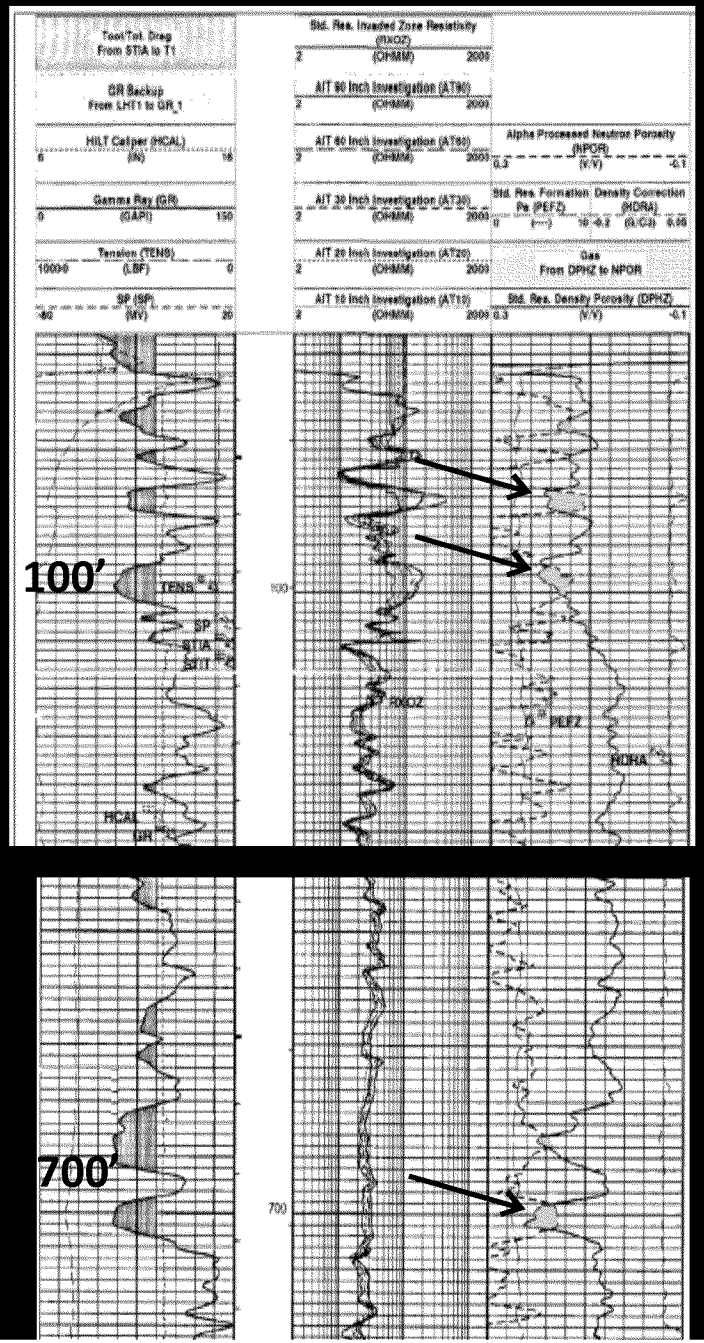


Neutron Density Logs:

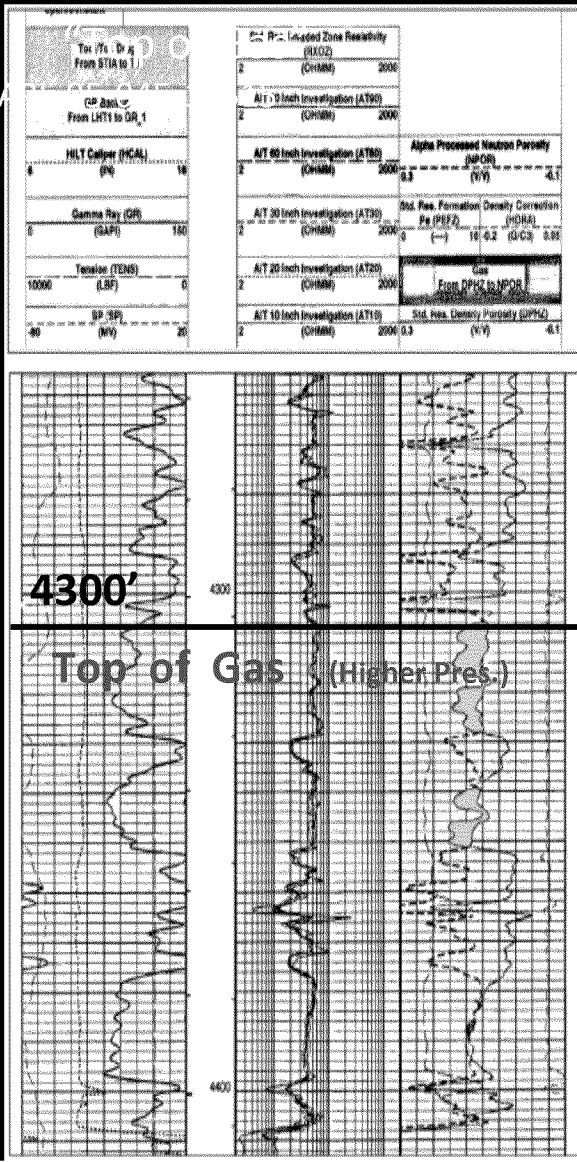
"Nuisance"
Shallow Wasatch Gas
API: 05-045-09148



API: 05-045-12515

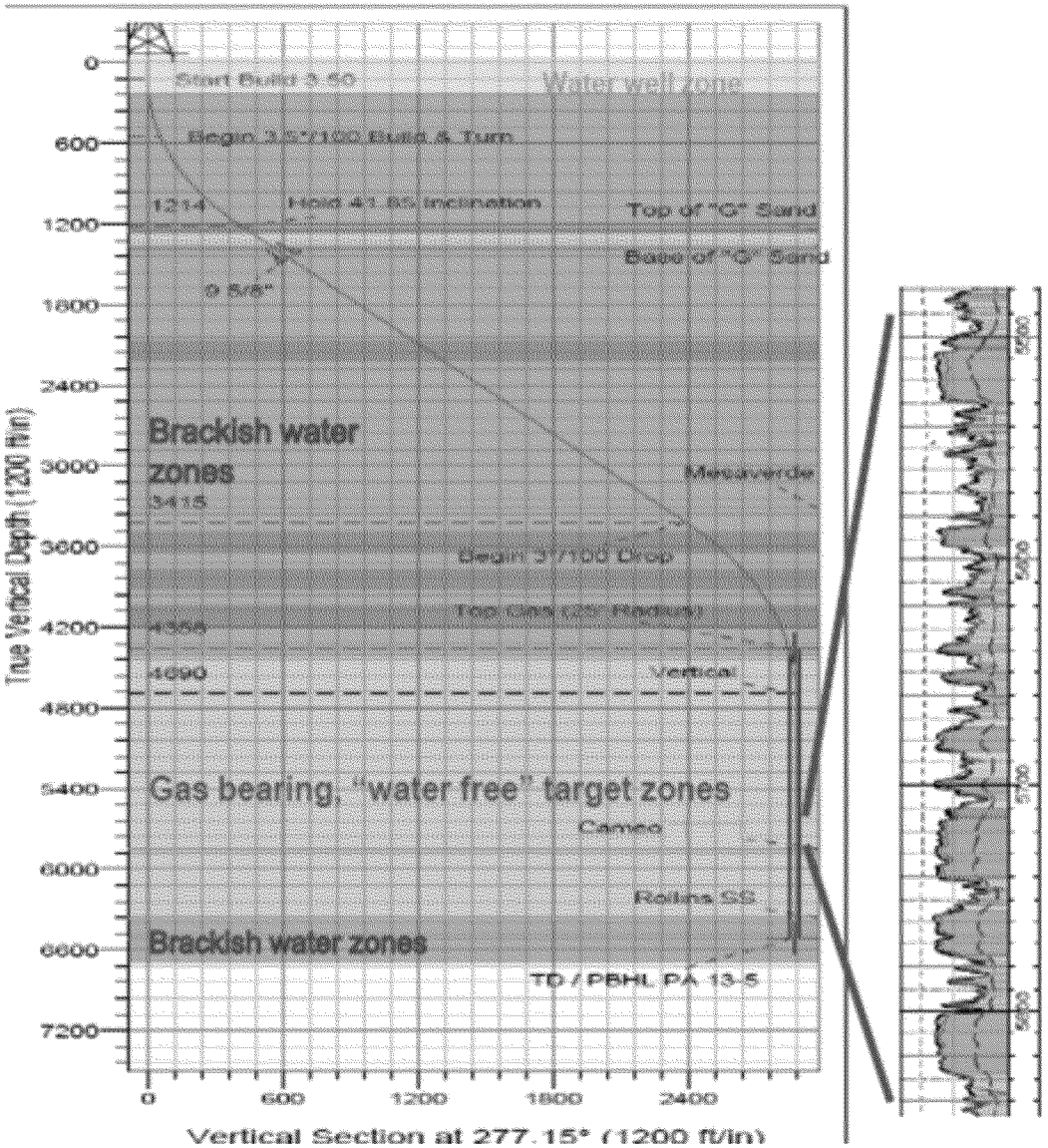


Williams Fork
non- commercial
"Top of Gas"
Above Commercial Gas



Piceance Basin Well Pad – Williams Fork Producing Wells

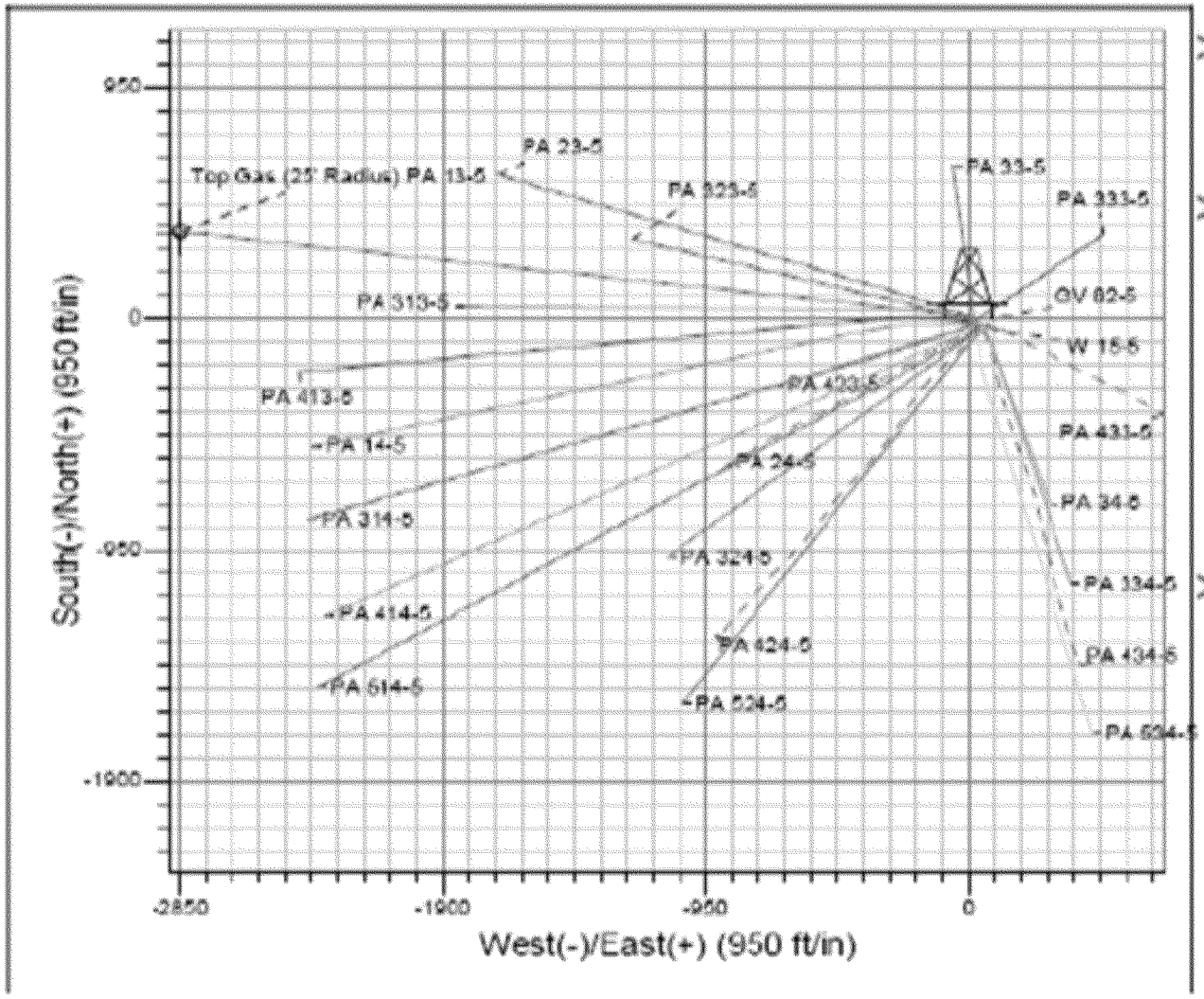
Typical S-shaped Directional Williams Fork Completions
(After First Vertical Well)



- Stacked lenticular sand/ shale sequence geology requires vertical penetration through gas bearing zones
- Low permeability, small sand bodies require 10 acre density to produce the gas resource

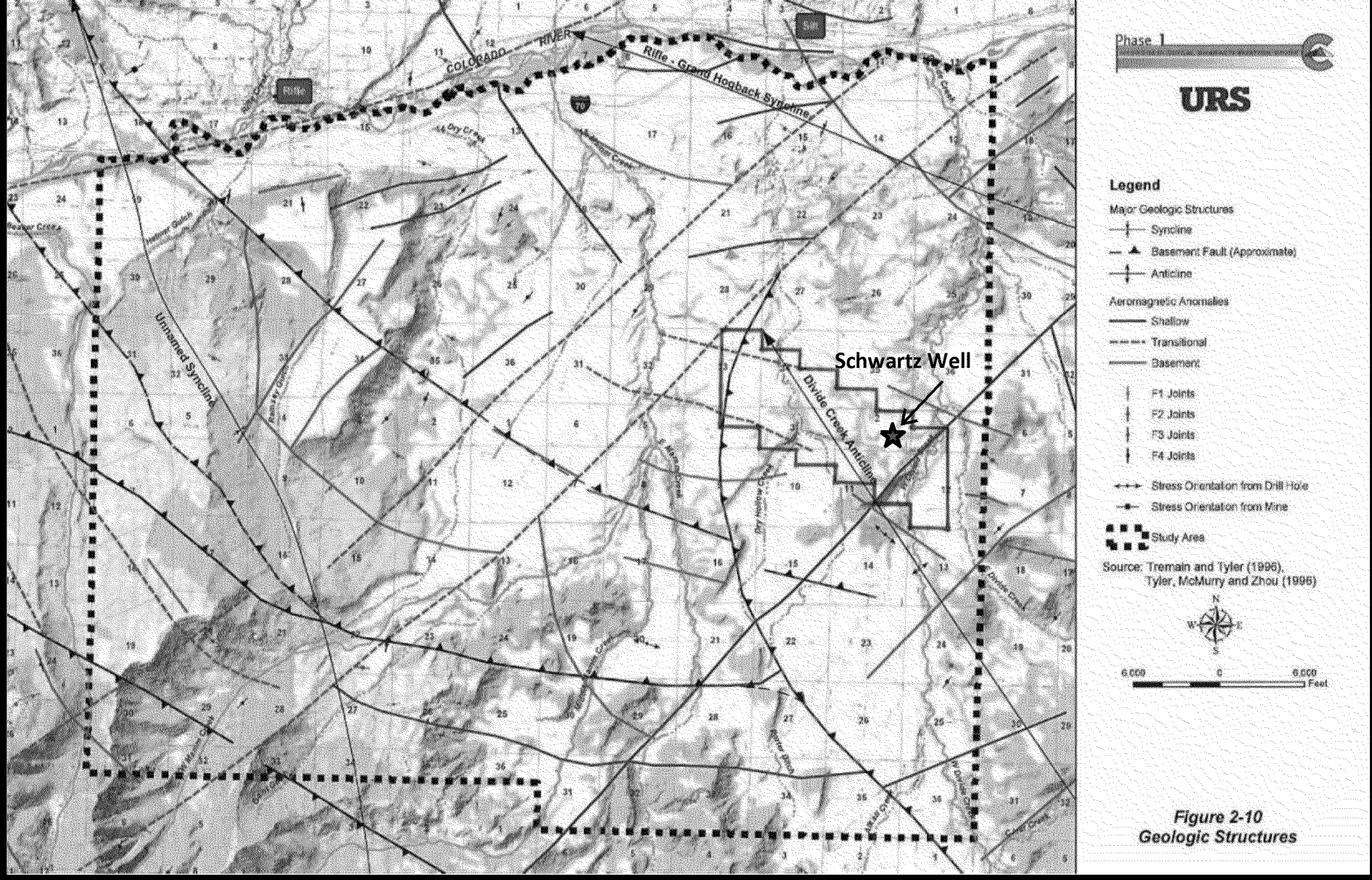
From EPA HF Workshop, Feb. 2011 (Foreman)

S-shaped Directional Wells (pad plan view)



- Plan view of typical pad
- Reach multiple bottom-hole (BH) locations from fewer pads (up to 24, 10-acre wells per pad).
- Typical target: 25' radius cylinder

From EPA HF Workshop, Feb. 2011 (Foreman)



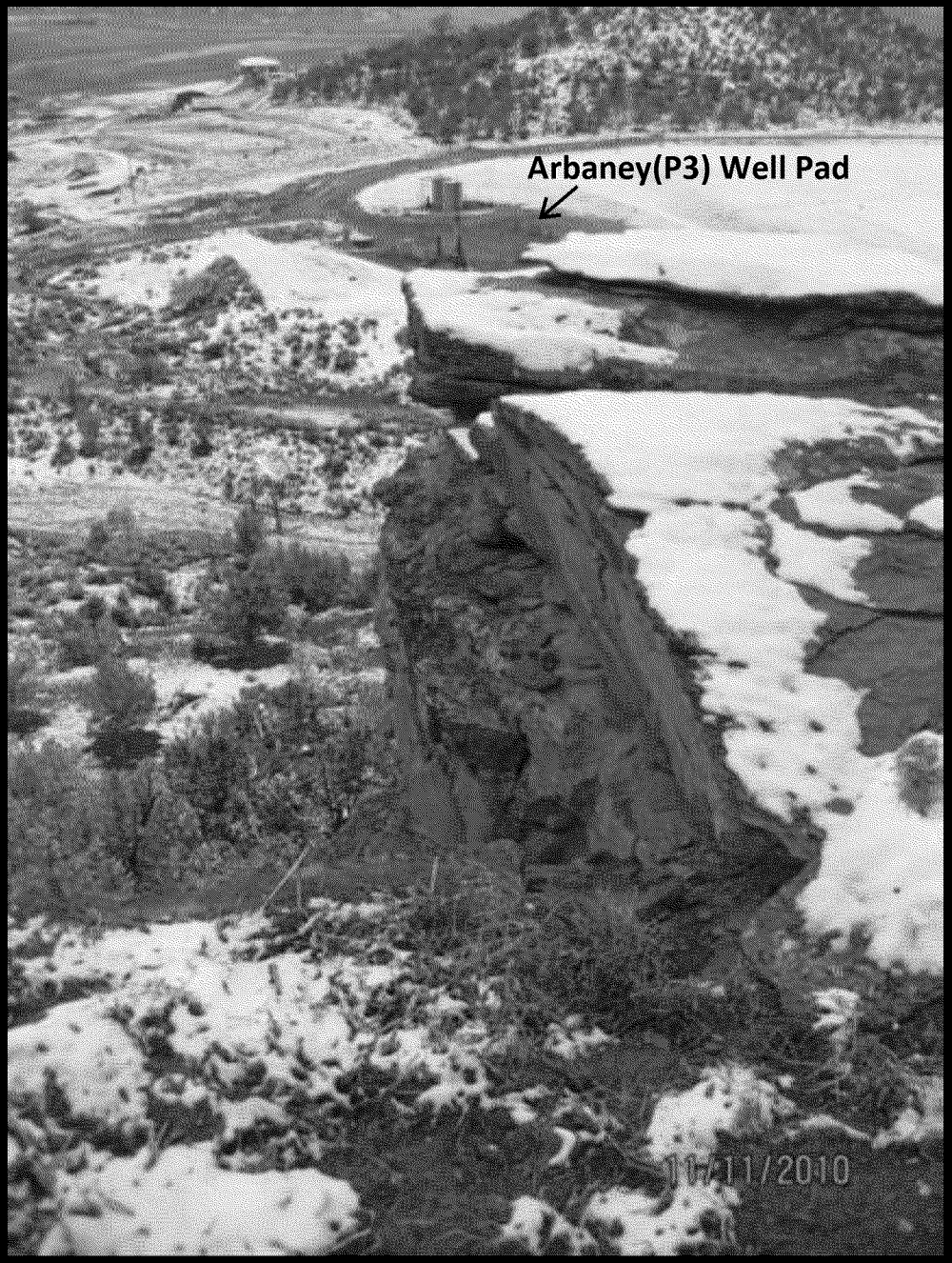
Mamm Creek study area with major structural elements w/ COGCC special drilling area (EMCPA) outlined in red. & Loc. of Schwartz Well

(From URS 2006 and Review of Phase II Hydrogeologic Study Prepared for Garfield County Thyne, 2008)

East Mamm Creek Producing Area (red outline in previous slide)

Field Measurement of Vertical Joint Face in the fracture/jointed Molina sandstone member of Wasatch Fm. (w/compass bearing)

From Water Group



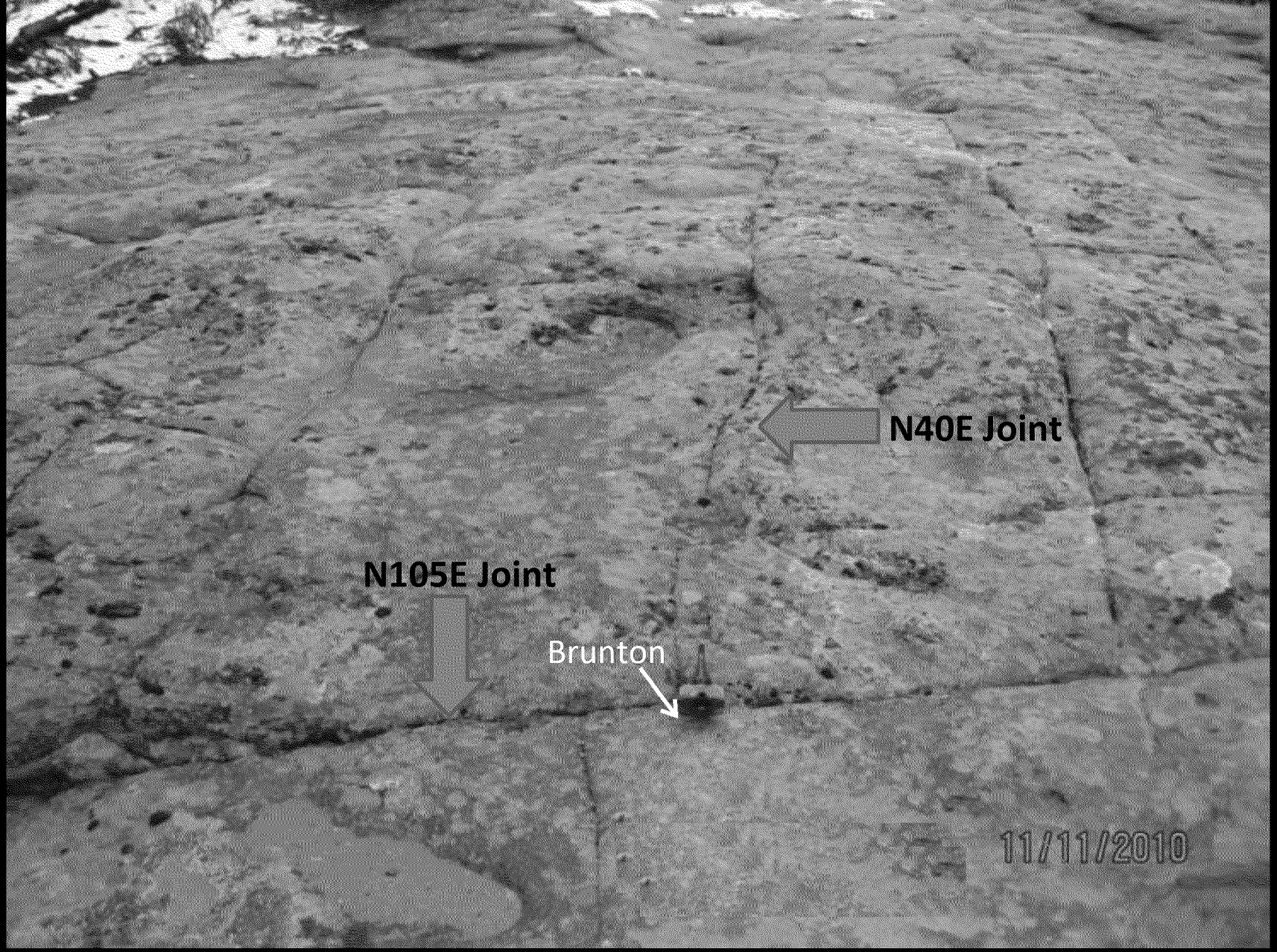
East Mamm Creek Prod./Policy Area (EMPCA)

Photo of an exposed joint face in Molina (like) Sandstone north of the Arbaney(P3) well pad.

(from Walter Group Report)

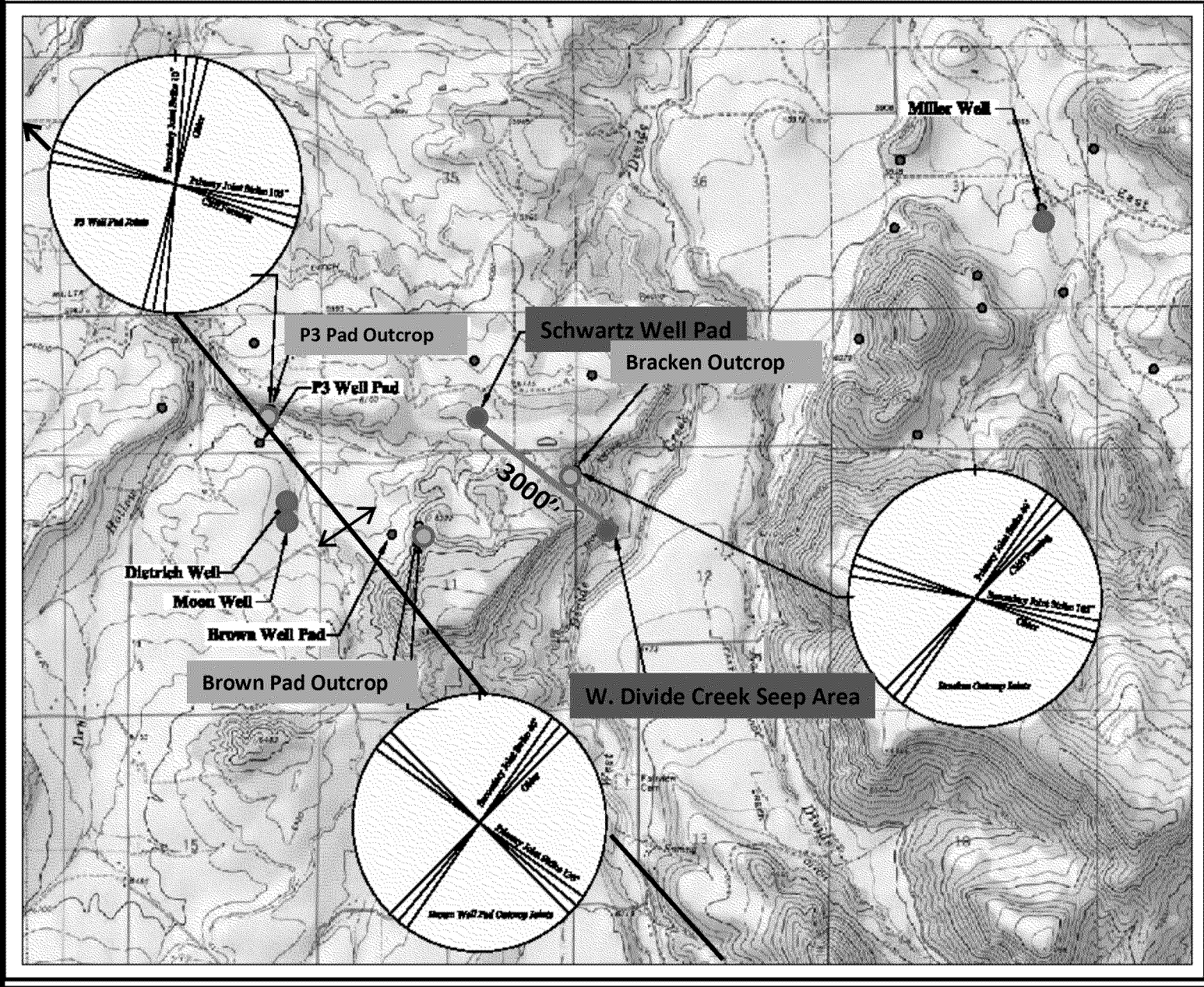
Sustained Elevated Bradenhead Pressures in 4 of P3 pad wells required pre-completion remediation.

(COGCC)



Joint sets in exposed surface sandstone outcrop of Molina (like) Sandstone Member of Wasatch Fm.

(from Walter Group study)



0 2,000

APPROXIMATE SCALE IN FEET

Explanation:

- Domestic Water Well Location
- Gas-Well Pad Location
- Gas Seep Location
- Outcrop Location

Note:

Joint strikes are shown with 10 degrees of splay to enhance their appearance on the figure.

Data Sources:

USGS, Gibson Gulch Colo. Quadrangle; 1987.
USGS, Hunter Mesa Colo. Quadrangle; 1987.
COGCC Online Data; 2010.

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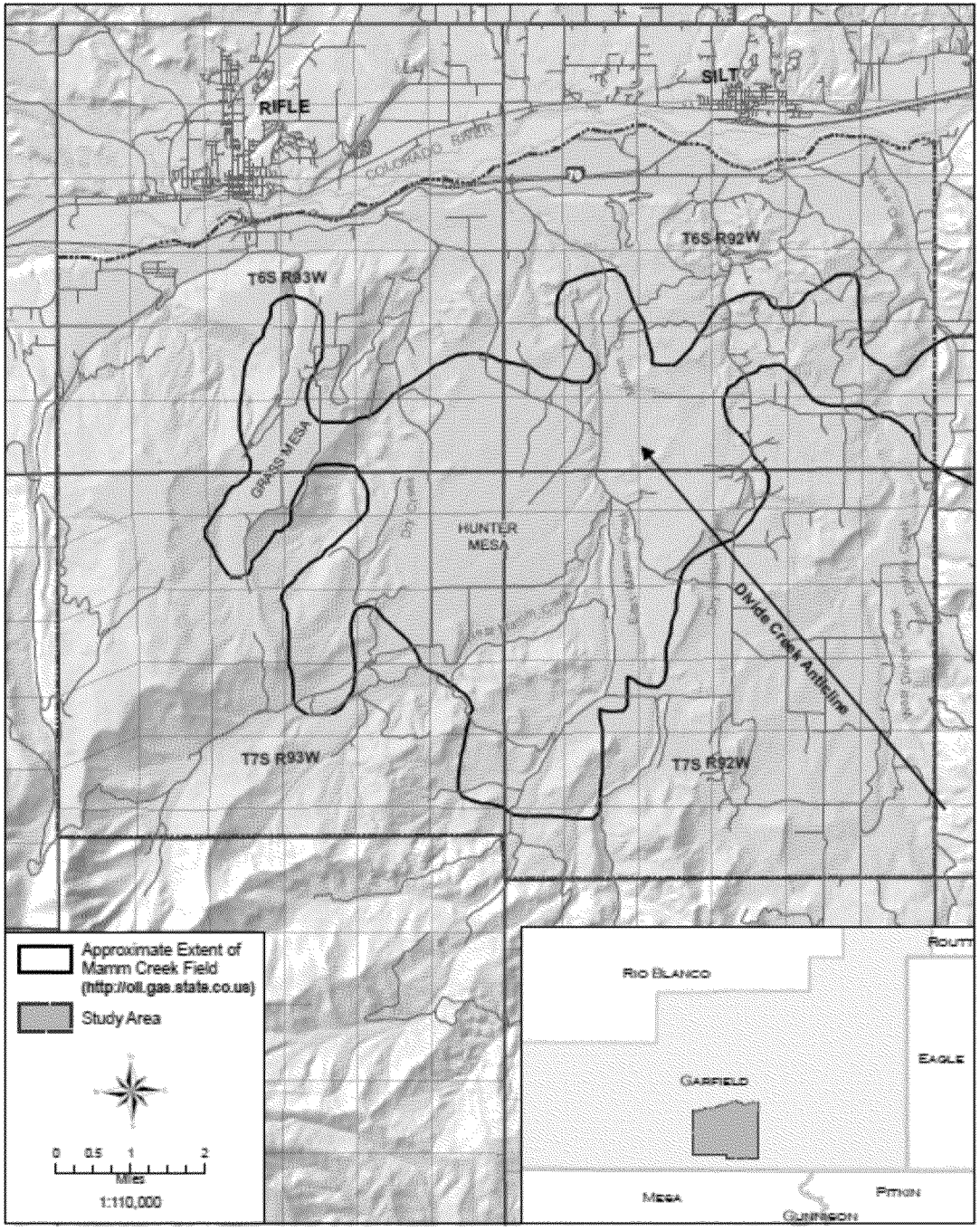
Joint Strike Measurements
Divide Creek Area Joint Study
South of Silt
Garfield County, Colorado

03/03/2011
Project No. 237-02-003

Figure 3

Joint Strike Measurements from 3 Outcrop Locations near Schwartz Well, West Divide Creek Seep, Water Wells and Well Pad Locations (EMCPA) (mod. from Walter Environmental Group)



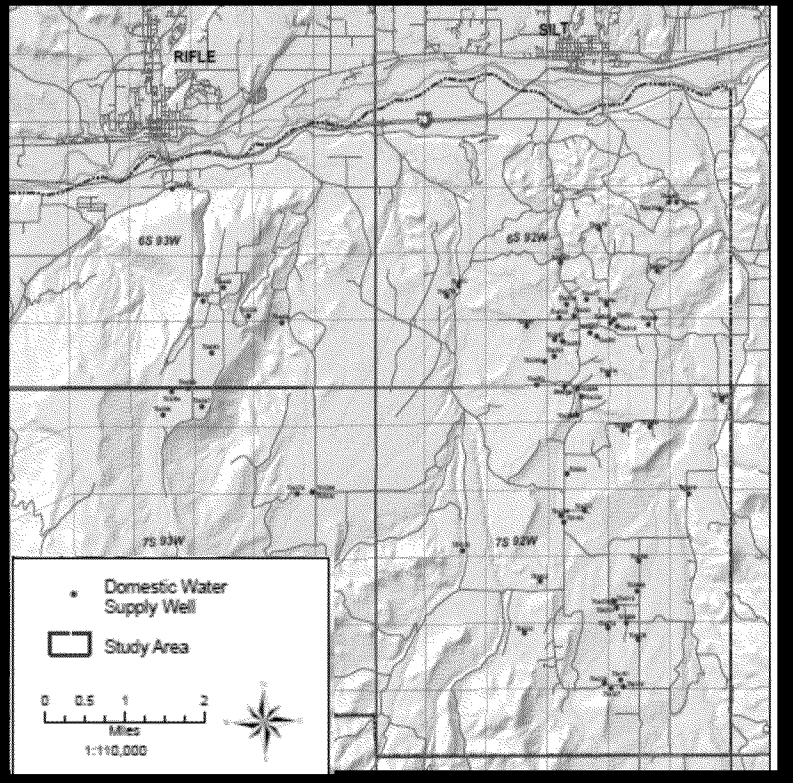
Note: Axis of Divide Creek Anticline Approximated based on Wasatch Formation Isopach Map (Figure 2-7; URS, 2006).

Figure 1.2. Mamm Creek Field Hydrogeologic Characterization Area of Investigation

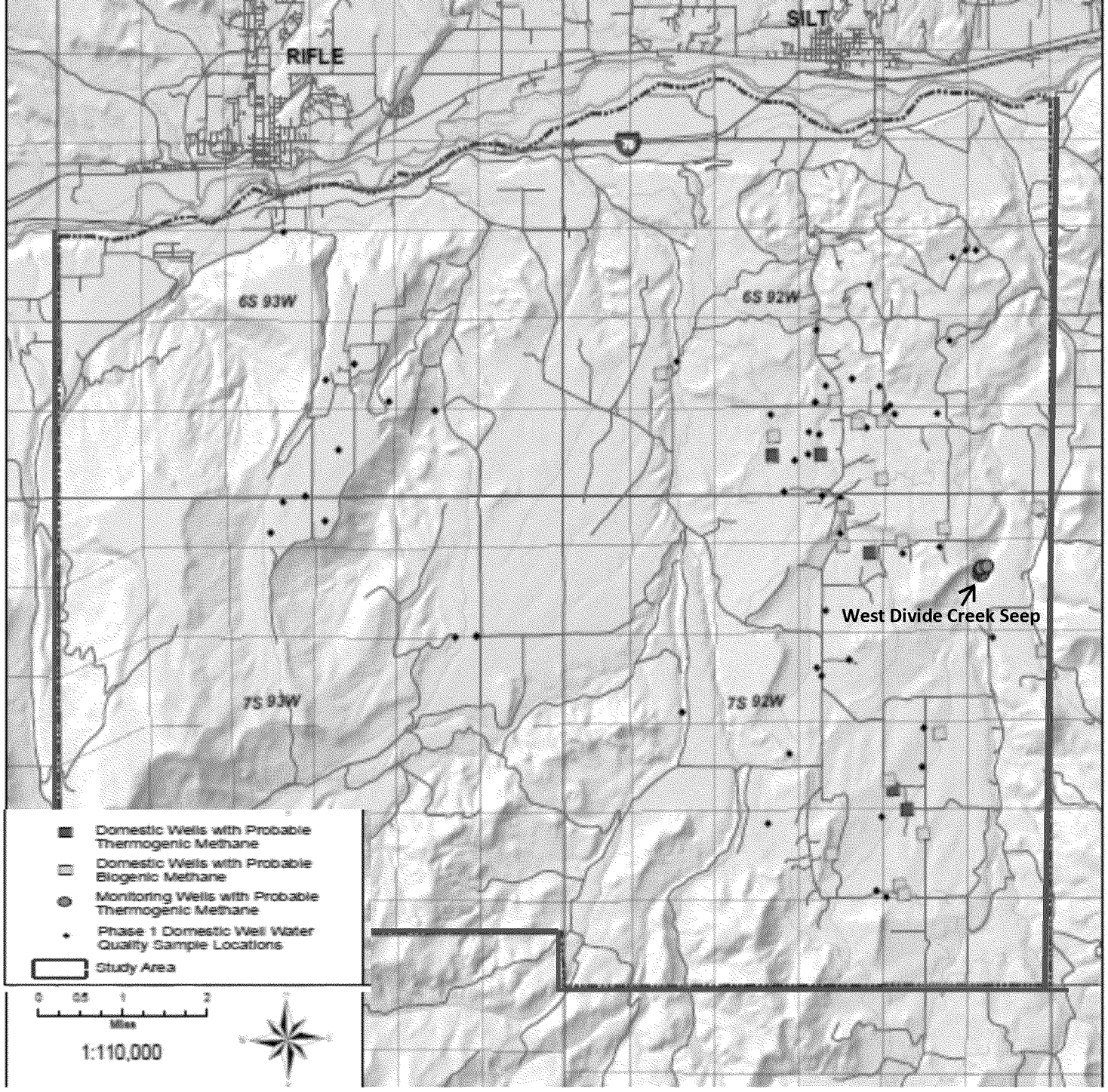
Outline of Mamm Creek Producing Area (Black Outline Area, 2005)

- 2100 + Gas Wells
- ~ 66 + Domestic wells (of the 500 WSW)

Locations of Domestic Wtr. Supply Wells



From URS 2005



Location of Domestic and Monitoring Wells in Mamm Creek Study Area with Probable Biogenic and Thermogenic Methane Sources. From Fig. 4.21 (SSPA, 2008)

<u>Various Plots:</u>

- **Water Chemistry (ion ratios)**
- **Carbon & Hydrogen Stable Isotopes of Methane**
- **Bernard Diagram**

- **6 domestic wells > 1 mg/L methane**

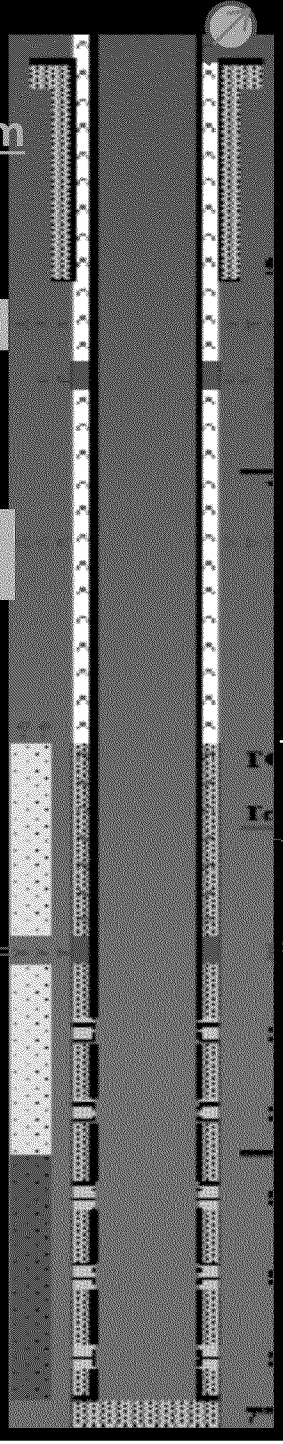
From SSPA, 2008

Schwartz 2-15B (02) Well and West Divide Creek Gas Seep General Characteristics and Relationship

- **Well location:** ~3000' NW of West Divide Seep (swse sec. 2 - T 7 S R 92W)
- **Field:** Mamm Creek (subsequently East Mamm Creek Producing Area, post-NTO)
- **Spud Date:** January 16, 2004 (in Wasatch)
- **Objective Formations:** Williams Fork and Rollins (Rollins not completed)
- **Formation Tops:** Wasatch (at surface), Williams Fork (at 3,217 feet), Rollins (at 6,299 feet) vertical well with total measured depth of 6,535 feet
- **Surface Casing:** 9 5/8" to 706' depth (water well depths to 450' in 1 mile radius)
- **Drilling History:**
  - Jan. 20 Lost Mud Circ. w/gas kick in Wasatch (1589' depth) – S.I. 1 hr to control kick
  - Jan. 27 Lost Mud Circ. w/gas kick in Williams Fork (4,328') – Shut In 8 hrs. to control kick
  - Feb. 6 Lost Circ. while running prod. casing – operations shut down for 7 hrs. to regain circ.

From COGCC

Schwartz 2-15B Wellbore Diagram



Bradenhead Pressure 500 – 661 psig prior to remediation

Wasatch: Surface to 3217’

----9 5/8” casing set at 706’ cemented to surface

To Shallower Fms. ======

======== to Divide Creek

Lost Circulation & gas kick 1543’ to 1589’ - Shallow kick extremely unusual

_____Wasatch “G”_____

Williams Fork Top 3217’

To Shallower Fms. === to Divide Creek

--------- TOC 4050’ TOC < 200’ above Top of Gas (post “fall back”)

Top of Gas 4132’

Pore pres. = 1072 psia
Gradient = 0.24 psi/ft

Gas entry after ======= primary cementing
Pore pres. = 1002 psia
Grad. = 0.23psi/ft. at 4456’

====== Lost Circulation and gas kick 4328’ while drilling

===== Frac Stage 5: 4458 ‘– 4633’ ; pp = 1002 psia; grad. = 0.23 psi/ft.

========= Stage 4: 4698’ – 4959’; pp = 1072 psia, grad. = 0.23 psi/ft.

Pressure regime change

========= Stage 3: 5207’ - 5338’; pp = 3033 psia; grad. = 0.57 psi/ft.

========= Stage 2: 5472’ - 5581’; pp = 3282 psia; grad. = 0.60 psi/ft.

========= Stage 1: 5827’ – 5960’; pp = 3497 psia; grad. = 0.60 psi/ft.

7” set at 6514’

Mod From COGCC

Con't. Schwartz well history

- **Production Casing Primary Cement Job:**
  - Cement initially circulated to surface (25 bbls)
  - Feb. 16,- CBL run shows TOC fallen to 4,050 depth (top of gas at 4,132' in WF - only 82 feet separation: TOC to TOG)
    -Temp. survey indicated upward gas migration under Shut-In cond. (cooling at 4,328')

- **Completion and Post-Completion Bradenhead Pressure Measurements:**

  - EnCana proceeded with frac stimulation of well through March
  - Final frac stage (5) at 4,458' to 4,633, No BH pres. build-up during frac but build up after frack
  - EnCana also observes BH pres. (515-650 psi) following completion activities and prior to remedial cement operations
  - EnCana submits Sundry Notice to COGCC on Mar. 23 (for remedial cement ops.)
  - COGCC approves Sundry Notice on Mar. 30
  - **April 1 - report of Gas Seep in West Divide Creek 3000' away**
  - During **Apr. 4 remedial cement job**, flowing BH pres. range 500 to 650 psi
  - Gas sample analytical results (isotopic & compositional) → Williams Fork gas is origin
    - Same for other nearby wells BH gas
  - BH pressure drops **to 0 psi after Remedial Cement Job** and gas flow to creek subsides dramatically w/in 8 days - Benzene levels in Creek drop after 12 days
  - EnCana agrees to 2 mile drilling moratorium while problems are investigated further
  - East Mamm Creek Production Policy area NTO established (revised drilling and completion/cementing)
  - Gas sampling (isotopic & compositional analysis) indicates Bradenhead gas is from Williams Fork (including other nearby wells)